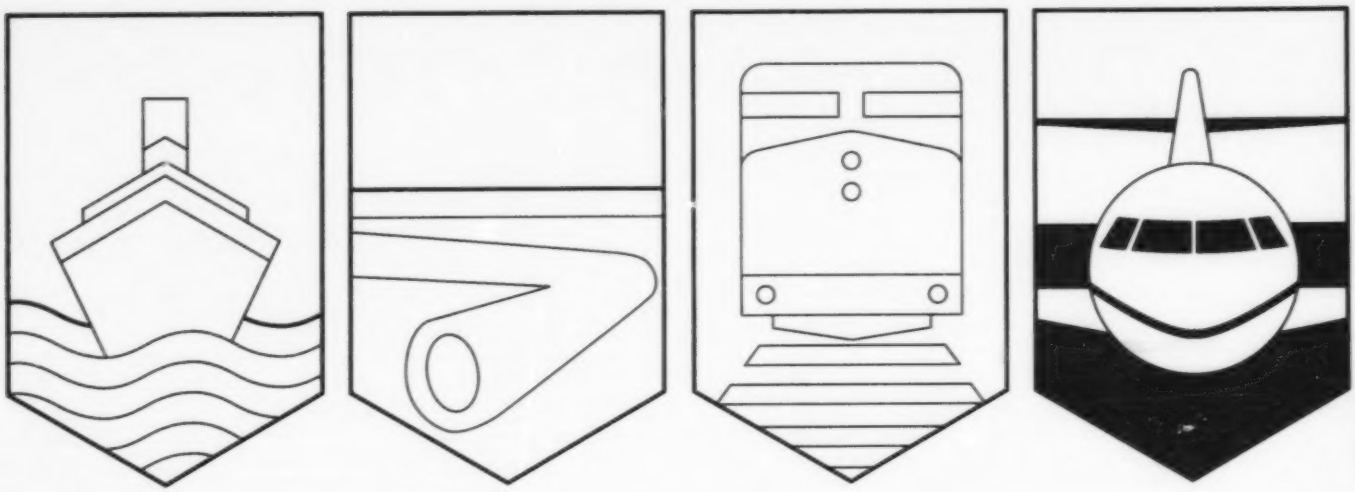
Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada



AVIATION OCCURRENCE REPORT

RISK OF COLLISION BETWEEN:
LOCKHEED L-1011-50 G-BEAM and
MCDONNELL DOUGLAS DC-8-62 N1805 and
BOEING 747-100 EI-BED
NORTH ATLANTIC
09 JULY 1989

REPORT NUMBER 89A0163

Canada

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TSB 15/91

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(To be released on 16 August 1991)

(Hull, Québec) - The Transportation Safety Board of Canada (TSB) has released its report on the multiple risk of collision incident that occurred over the North Atlantic on 09 July 1989.

British Airways Flight 094, a Lockheed L-1011-50, was en route from Montreal to London. While eastbound over the North Atlantic at flight level 350, it began deviating south of its assigned track. While off course, BA Flight 094 had three risks of collision with two aircraft, a McDonnell Douglas DC-8-62 and a Boeing 747-100; it also had losses of separation with two additional aircraft.

The Transportation Safety Board determined that a two-degree input error had been made during programming of the Flight Management System/Inertial Navigation System (FMS/INS) for the North Atlantic crossing. This caused the aircraft to begin deviating off course at 50 degrees west longitude. The INS cross-checks were not conducted at 50 degrees west, and the error went undetected, resulting in a 120 nautical mile deviation south of the assigned North Atlantic Track. A weakness in the British Airways L-1011 fleet's system of cross-checking contributed to the seriousness of this occurrence.

Since this occurrence, British Airways has informed the Board that changes to their operating procedures and manuals have been approved by the United Kingdom Civil Aviation Authority (CAA). These changes were made by British Airways to address the identified deficiencies, and they are reportedly now in effect.

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At present, there is no real-time air traffic control surveillance system covering the airspace over the North Atlantic, and separation of air traffic is accomplished through procedural controls. This current method of control was not cited as a factor in this incident; however, the installation of a real-time surveillance system could possibly have prevented the losses of separation between the British Airways L-1011 and the other aircraft. A system of this type would have allowed visual monitoring of the traffic by an air traffic controller and, hence would have provided an increased capability for detecting potential conflicts.

This inability to monitor directly air traffic over the North Atlantic was previously identified in the Canadian Aviation Safety Board (CASB) Report on a Special Investigation Into Air Traffic Control Services In Canada (March 1990). In its response, Transport Canada indicated that actions were being taken to correct the situation through the International Civil Aviation Organization (ICAO) Future Air Navigation System Committee. They had established a developmental program to investigate procedural issues regarding a satellite-based Automatic Dependent Surveillance system (ADS). The ADS system would allow suitably equipped aircraft to automatically transmit their position via a satellite link to a ground monitoring station.

The Transportation Safety Board of Canada is an independent agency operating under its own Act of Parliament. Its sole aim is the advancement of transportation safety. It conducts investigations of occurrences, makes findings, identifies safety deficiencies, conducts safety studies, and makes recommendations designed to prevent further occurrences. It is not the function of the Board to assign fault or determine civil or criminal liability.

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The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

AVIATION OCCURRENCE REPORT

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SYNOPSIS

British Airways Flight 094 was eastbound over the North Atlantic when it began deviating south of its assigned track at 50 degrees west longitude. While off course, BA Flight 094 had three risks of collision with two aircraft and had losses of separation with two other aircraft at flight level 350.

The Transportation Safety Board of Canada determined that a two-degree input error had been made during programming of the Flight Management System/Inertial Navigation System (FMS/INS) for the North Atlantic crossing. This error caused the aircraft to begin deviating off course at 50 degrees west longitude. The INS cross-checks were not conducted at 50 degrees west, and the error went undetected, resulting in a 120 nautical mile deviation south of the assigned North Atlantic Track. A weakness in the British Airways L-1011 fleet's system of cross-checking contributed to the seriousness of this occurrence.

14 May 1991

Ce rapport est également disponible en français.

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1.0 FACTUAL INFORMATION

1.1 History of the Flight

British Airways (BA)* Flight 094, a Lockheed L-1011-50, departed Mirabel Airport in Montreal, Quebec on 09 July 1989, at 0203 Coordinated Universal Time (UTC)**, on the second leg of a scheduled international flight from Detroit, Michigan to London's Heathrow Airport.

Richair Flight 805, a DC-8-62, departed Orlando, Florida on 08 July 1989, at 2334 UTC, on an international charter flight to Stansted, England.

Aer Lingus Flight 106, a Boeing 747-100, departed New York's JFK Airport on 09 July 1989, at 0133 UTC, on a scheduled international flight to Shannon, Ireland.

As the aircraft were approaching the Atlantic Ocean, Gander Area Control Centre (ACC) cleared the three aircraft on different routes parallel to and separated from each other by 60 nautical miles*** (nm) or one degree of latitude (lat). All three aircraft were at flight level (FL) 350.

At 50 degrees west longitude (long), BA Flight 094 began deviating to the south of its assigned track until it was 120 nm south of course at 40 degrees west. BA Flight 094 then turned northeast and regained the proper track at 56 degrees north and 30 degrees west.

While off course, BA Flight 094 came into conflict with both Richair 805 and Aer Lingus 106. In addition, BA Flight 094 had losses of separation with two other aircraft at FL350 on tracks south of Aer Lingus 106.

BA Flight 094 came into conflict with Richair 805 as BA Flight 094, heading southeast, crossed Richair 805's track with approximately four minutes separation. This loss of separation occurred at 0426 UTC, during the hours of darkness, over the North Atlantic, at an approximate position of lat 53°10'N, long 45°00'W.

The conflict with Aer Lingus 106 occurred 120 nm south of course, when BA Flight 094 joined the track of Aer

* See Glossary for all abbreviations and acronyms.
** All times are UTC unless otherwise stated.
*** Units are consistent with official manuals, documents, reports, and instructions used by or issued to the crew.

Lingus 106 with one minute separation. This loss of separation occurred at 0443 UTC, during the hours of darkness, over the North Atlantic at lat 53°00'N, long 40°00'W.

BA Flight 094, heading northeast at 54°37'N, 35°00'W, once again crossed the track of Richair 805. Richair 805 made visual contact with BA Flight 094 as it passed approximately two nm ahead and reported the occurrence to Gander Flight Service Station (FSS) on high frequency (HF) radio. The second loss of separation with Richair 805 occurred at 0513 UTC, during the hours of daylight, over the North Atlantic at lat 54°37'N, long 35°00'W.

The two losses of separation which occurred south of the track followed by Aer Lingus 106 were one of 9 minutes when 10 minutes separation was required, and one of 12 minutes when 15 minutes separation was required.

1.2 Injuries to Persons

Not Applicable.

1.3 Damage to Aircraft

Not Applicable.

1.4 Other Damage

Not Applicable.

1.5 Personnel Information

1.5.1 British Airways Flight 094

	Pilot-In-Command	Co-Pilot
Age	N/A	N/A
Pilot Licence	N/A	N/A
Medical Expiry Date	N/A	N/A
Total Flying Time	N/A	N/A
Total on Type	N/A	N/A
Total Last 90 Days	N/A	N/A
Total on Type Last 90 Days	N/A	N/A
Hours on Duty Prior to Occurrence	7 hr	7 hr
Hours off Duty Prior to Work Period	23 hr	23 hr

All three crew members were qualified to conduct the flight. The captain, who had approximately 40 North Atlantic crossings all as a captain, was in the left seat and was the non-flying pilot. The first officer, who was on his fourth North Atlantic trip, was in the right seat and at the controls. The flight engineer had 12 years experience crossing the North Atlantic.

The day before the occurrence, this crew had flown together from London, England to Detroit, Michigan. They arrived in their Detroit hotel at 1800 eastern daylight time (EDT). They went to bed at about 2330 EDT, and awoke at about 0730 EDT. After breakfast and a morning of sightseeing, both pilots rested in their hotel rooms for the afternoon, but did not sleep. The crew left together for the airport at 1730 EDT. Another four hours transpired between Detroit and the Flight Management System (FMS) programming cycle in Montreal. In Montreal, from the time they began their trip westbound, the crew had eight hours sleep and three hours prone rest in the previous 43 hours. By the time they reached 50 degrees west, that time had stretched to 46 hours. The crew started their work cycle having been awake for 10 hours and had been awake 17 hours by the time they reached 50 degrees west.

1.6 Aircraft Information

1.6.1 British Airways Flight 094

Manufacturer	Lockheed
Type	L-1011-50
Year of Manufacture	N/A
Serial Number	N/A
Certificate of Airworthiness	Valid
Total Airframe Time	N/A
Engine Type	N/A
Maximum Allowable Take-off Weight	N/A
Recommended Fuel Type(s)	Jet B

The aircraft was properly equipped for navigation on the North Atlantic.

1.7 Meteorological Information

All the involved flights were flying in visual meteorological conditions.

1.8 Aids to Navigation

1.8.1 The North Atlantic Organized Track System

High level air traffic on the North Atlantic consists primarily of two unidirectional flows: westbound during the day, and eastbound during the night. A North Atlantic Organized Track System (NAT/OTS) is in place. This airspace usually consists of five or six tracks, each assigned with alphabetic designators and laterally separated by 60 nm. The positions of these tracks change daily and are based on the wind-related minimum time track between New York and London.

1.8.2 Minimum Navigation Performance Specifications

Minimum Navigation Performance Specifications (MNPS) airspace is that airspace within which users must meet certain minimum navigation equipment requirements. The NAT/OTS is always within MNPS airspace.

1.8.3 North Atlantic Navigation Within MNPS

The navigation systems used by individual aircraft are based upon self-contained airborne navigation capability; no ground-based aids, data links, or satellite radar are available. The MNPS airborne navigation equipment standard and the operating procedures are established by an international committee of North Atlantic airspace users. This committee is known as the North Atlantic Systems Planning Group (NAT/SPG) and works under the auspices of the International Civil Aviation Organization (ICAO). NAT/SPG makes its recommendations known to the ICAO contracting states through the North Atlantic MNPS Airspace Operations Manual, printed on behalf of the NAT/SPG by the United Kingdom, Civil Aviation Authority (CAA). It is the responsibility of the contracting state to ensure that the procedures contained in the manual will be complied with by their carriers before authorizing carriers to fly in MNPS airspace.

British Airways was approved by the CAA to fly in MNPS Airspace. BA Flight 094 was equipped with three Inertial Navigation Systems (INS) for long-range navigation. In addition, an FMS was used. INS navigation equipment, as well as other self-contained navigation systems, is different from ground-based navigation systems because of the requirement to input navigation data. A unique aspect of North Atlantic navigation is the daily changing of the organized track structure; therefore, waypoint latitude and longitude data cannot be stored and must be manually entered for each North Atlantic flight. To ensure that an airplane

is on the assigned track, there must be accurate data input and continuous monitoring of the navigation system by use of navigation cross-check procedures.

On BA L-1011s, the FMS was controlled through a control and display unit (CDU) located on the forward left side of the centre console. The captain's INS/CDU is located immediately to the left of the FMS/CDU. The first officer's INS is located on the forward right side of the centre console. The third INS/CDU is located in the rear section of the centre console.

1.9 Communications

Aircraft flying across the North Atlantic beyond ground-based very high frequency (VHF) reception range use HF radio for communication. All communications are made through an FSS located on one side or the other of the North Atlantic. In Gander, an FSS, collocated with the ACC, handles the HF communications, relaying information between the air traffic controllers and the pilots. There is no direct pilot/controller communication capability. Pilots continuously monitor 121.5 megahertz (MHz), VHF, over the North Atlantic in case of the need for emergency communications between aircraft. Pilots do not listen continuously to HF because of noise and static, but a selective call system (SELCAL) generates a cockpit tone when some agency, such as an FSS, is calling an aircraft.

The HF communications facilities were operating normally on 11 July 1989 but were subject to the usual difficulties associated with HF communication, including busy frequencies and signal propagation problems.

1.9.1 Air Traffic Control Clearances

An eastbound trans-atlantic flight receives an air traffic control (ATC) clearance in three stages: the domestic departure clearance, the oceanic clearance from Gander ACC, and further European clearance approaching landfall.

The clearances issued by Gander ACC to BA Flight 094, Richair Flight 805, and Aer Lingus 106 were correct and met required separation standards. All clearances were accurately read back.

BA Flight 094 was cleared via track V, Richair 805 was cleared via track W, located 60 nm south of track V, and Aer Lingus 106 was cleared via track X, located 120 nm south of track V.

On 09 July 1989, the coordinates of these tracks were as follows:

Track V - 53°N/50°W; 55°N/40°W; 56°N/30°W; 56°N/20°W;

Track W - 52°N/50°W; 54°N/40°W; 55°N/30°W; 55°N/20°W;

Track X - 51°N/50°W; 53°N/40°W; 54°N/30°W; 54°N/20°W.

1.9.2 Progress Reports

For eastbound flights, aircraft are required to make progress reports when crossing the following positions:

Coast-out point (the point where aircraft enter oceanic airspace), 50 degrees west, 40 degrees west, 30 degrees west, 20 degrees west, and 15 degrees west.

All three aircraft made the required and correct progress reports at 50, 40 and 30 degrees west, except for BA Flight 094. At 40 degrees west, the crew of BA Flight 094 reported their position as 44 degrees north, 40 degrees west at 0444 UTC, FL350, estimating 56 degrees north, 30 degrees west at 0528 UTC. When queried by Gander FSS concerning the 44 degrees north coordinate, the pilot corrected it to 55 north. The pilot's estimated elapsed time between 40 and 30 west was 44 minutes.

The controllers estimate for BA Flight 094 at 56 degrees north, 30 degrees west was 0522 UTC, an elapsed time of 38 minutes. A difference of six minutes existed between the pilot estimate and the computer-generated controller estimate.

If a discrepancy of five minutes or more exists between the pilot's and the controller's estimates in airspace controlled by Gander ACC, the controller shall ask the pilot to verify his/her estimate. This is a recent change implemented by Air Traffic Services from a Canadian Aviation Safety Board (CASB) recommendation resulting from the investigation of the Delta/Continental "near collision" of July 1987.

1.10 Aerodrome Information

Not Applicable.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorders (CVR)

The CVRs, in all three aircraft, operate on a 30-minute continuous loop tape. The CVRs continued to operate after the occurrence, and all information regarding the occurrence was lost. The CVRs were not analyzed.

1.11.2 Digital Flight Data Recorders (DFDR)

The DFDR and the quick access recorder (QAR) from BA Flight 094 were analyzed by the United Kingdom, Department of Transport, Accidents Investigation Branch, the British Airways Air Safety Branch, and the TSB. The QAR contained INS geographical information, headings, airspeeds, altitudes, and other information. This recorder confirmed that BA Flight 094 had deviated 120 nm south of its cleared track. Because of this clear confirmation, the TSB did not analyze the DFDRs from the other aircraft.

1.12 Wreckage and Impact Information

Not applicable.

1.13 Medical Information

There was no evidence that incapacitation or psychological factors affected the crews performance.

Flight-crew rest and its effect on this flight is discussed in sections 1.5.1 and 2.7 of this report.

1.14 Fire

Not applicable.

1.15 Survival Aspects

Not applicable.

1.16 Tests and Research

None.

1.17 Additional Information

The first officer was designated the flying pilot for the Montreal-London leg of the flight. As flying pilot, he was responsible for programming the route into the INS using the FMS. The crew is provided with a computerized flight log called a SWORD. A NAT-TRACK message is sent to all operators requesting it, between 1300 and 1400 UTC every day, advising them of the NAT/OTS for the eastbound traffic. The period of validity is from 0100 to 0800 UTC. The SWORD was checked by the crew before the flight and found to be accurate for the intended flight. The first officer programmed the complete route to London, copying from the SWORD, while they were on the ramp at Montreal. At this time, the first officer programmed a two-degree coordinate error into the INS.

The captain, as the non-flying pilot, was responsible for checking the programmed route against the SWORD for accuracy. The first officer did a gross distance check and found a large error. The error was determined to be an unintentional substitution of the Moscow identifier for that of Manchester, England. The first officer corrected this error, and the new total distance was considered reasonable. Neither pilot detected the coordinate error at this time.

Flight deck activity was routine during the programming and checking of the INS. There were the usual interruptions, but nothing unusual to distract the crew.

The FMS stores waypoints with known geographical positions (e.g.: very high frequency omni-directional ranges (VORs), non-directional beacons (NDBs), intersections, and ramp gates) in its data base. When the pilot uses the location identifier as a label to identify the waypoint to the FMS, the FMS automatically selects the correct coordinates for that waypoint from its data base and transfers it to the INS system.

When programming an oceanic waypoint, no such location identifiers exist, so all British Airways' crews must choose a representative label for the waypoint. British Airways teach their pilots to label (identify) oceanic waypoints with the principal digits of the actual coordinate. The crew would label latitude 53 degrees north, longitude 50 degrees west, as 53N50, and continued this label convention for the entire crossing.

When a pilot has selected a label, the FMS looks for the label in its data bank. If the FMS cannot recognize the label, it asks the pilot to input the actual coordinates of the waypoint. In the BA L-1011 fleet, the FMS always has to ask for the oceanic coordinates because there is not enough memory in the data base to store all the North Atlantic waypoint combinations along with the known waypoints already stored there.

The actual coordinates programmed by the first officer of BA Flight 094 for this flight are depicted below. The program is listed by the label used and the actual coordinate programmed for that label.

FMS Label	Actual Coordinates Programmed
53N50	5300.0 north, 5000.0 west
55N40	5300.0 north, 4000.0 west
56N30	5600.0 north, 3000.0 west

The incorrect north coordinate was programmed for longitude 40 west. The captain confirmed the programming by checking the FMS index page, which is the page that shows the waypoint labels, not the actual waypoint coordinates. As described earlier, the labels and the actual programmed coordinates can differ. The captain did not check the individual coordinates and did not discover the input error before take-off.

With the input error undiscovered, the aircraft started deviating south of its cleared track, at 50 degrees west, and proceeded to 53 degrees north, 40 degrees west, at which point it was 120 nm south of course, then flew to 56 degrees north, 30 degrees west, regaining the assigned course there. BA Flight 094 crossed North Atlantic Track W, joined North Atlantic Track X for a short while, and then recrossed North Atlantic Track W.

Between St. Anthony and 50 degrees west, Gander ACC cleared BA Flight 094 to maintain FL350 at a speed of Mach 0.82. The crew reported that they had difficulty maintaining FL350 because the aircraft was heavy, and Mach 0.82 was too slow, putting the aircraft near the low end buffet. The problem was further complicated by a slipping clutch on the number one auto-throttle. The captain determined that the aircraft was within the approved operating envelope, but was near the edge. He became concerned about possible turbulence, a loss of airspeed, and the throttle problem, so he assumed control of the aircraft until they could receive a

clearance to cruise at Mach 0.84. During this time, the captain was responsible both for flying the aircraft and conducting navigation cross-checks.

While flying the airplane, the captain did not conduct INS cross-checks at 53 degrees north, 50 degrees west, and the input error remained undetected at that point.

Shortly after passing 50 degrees west, the captain, with the approval of the other two flight deck members, elected to take a flight deck rest. This legal procedure allows a crew member to rest, while remaining in his/her seat, but not active in flying the aircraft or monitoring flight progress.

The first officer conducted the required cross-checks during waypoint passage at 40 degrees west and discovered the error. The cross-check revealed that the aircraft was 120 nm south of track. It took approximately 15 minutes for the crew to sort out and confirm their position, and by then the FMS was steering the aircraft back to course toward 56 degrees north, 30 degrees west.

1.17.1 The Aircraft's INS Equipment

British Airways determined, shortly after BA Flight 094 arrived in London, that the error was an INS input error. The company, therefore, had no reason to suspect the aircraft equipment and returned the aircraft to service.

1.17.2 Gross Navigation Errors Using Self-Contained Equipment

A gross navigation error is defined in the North Atlantic MNPS Airspace Operations Manual as a deviation of more than 25 nm from the prescribed track. An examination of previous occurrences involving gross navigation errors over the North Atlantic indicates that data input errors are a factor in the majority of cases, in particular those errors involving the use of INS.

1.17.3 British Airways INS/FMS Training - Lockheed L-1011

The INS/FMS training for British Airways L-1011 crews is part of the type qualification training. The INS procedures are further checked on route-check flights.

1.17.4 MNPS Operations Manual

A summary of the cross-check procedures contained in the MNPS Operations Manual is as follows:

1. Plot the waypoints entered into the navigation system on a map or a chart for the area to be traversed;

2. Data entered by one crew member to be verified by another crew member;

3. Match predicted distance between inserted waypoints against predicted distances on the aircraft's flight plan;

4. Match navigation system present position against the coordinates of known ground-based navigation aids before crossing the outbound gateway;

5. Match the coordinates of waypoints against the flight plan, both when crossing the waypoints and approximately 10 minutes following the waypoint.

6. Match estimated time and distance between waypoints against those parameters predicted on the flight plan; and,

7. Plot actual position on a chart, 10 minutes after waypoint passage, to compare actual position with required position.

In addition, the manual puts a strong emphasis on the fact that errors do occur and must be guarded against. The manual goes to great lengths to expand on procedures, both to give instruction and to emphasize their importance.

1.17.5 British Airways Fleets

The various fleets within British Airways are managed separately, with individual chief pilots. The Boeing 747 and the Lockheed L-1011 fleets operate with different manuals, including long-range INS procedures. While some of these procedures are different because of equipment, British Airway's INS cross-check procedures are not standard across all their fleets.

The Boeing 747 fleet flying manual and training manual closely emulated the MNPS Operations Manual in their instructions to flight crews. The manual provided strong direction on INS use by the mandatory use of flight progress charts on the flight deck, by programming the number three INS independent of the

other two INS sets, by placing emphasis on the requirement to cross-check, by giving mandatory direction on reporting gross navigation errors, and by giving expanded detailed instructions concerning INS navigation and cross-checking.

1.17.6 British Airways L-1011 Flying Manual

The BA L-1011 flying manual stated:

1. Before takeoff; data entered by one crew member to be verified by another crew member, and check for a gross mileage/time error against the flight SWORD.

2. Over a waypoint; check next waypoint position (lat/long), compare desired track with SWORD, and compare time/distance with SWORD.

In addition to these cross-checks, the BA L-1011 flying manual states that the crews shall normally leave their INS in the following display modes: number 1 in next waypoint position, number 2 in track/distance, number 3 in cross-track error.

The number 3 INS set receives its waypoints from the FMS. If the FMS contains an error, the number 3 INS will also have the same error.

The BA L-1011 procedures, as portrayed in the BA L-1011 flying manual and approved by the CAA, are not as extensive as those described in the MNPS Operations Manual or the British Airways Boeing 747 manuals.

1.17.7 Navigation Error Reporting

The MNPS Operations Manual makes several references to dealing with navigation difficulties. Regardless of the origin of the difficulty, the manual states "ATC should be contacted" whenever navigation degradation is suspected or known.

British Airways L-1011 flying manual makes no reference to error reporting. A North Atlantic Flight Progress Chart is provided to British Airways crews. On the back of this chart, it is written, "Aircraft must maintain track accurately. All deviations must be advised to ATC." This chart, however, is optional and BA L-1011 crews do not have to carry it in the cockpit. The flying manual makes no reference to reporting navigation difficulties to ATC. BA Flight 094's crew was carrying a flight progress chart; however, not all members were aware that this information was on the back.

The captain did not report the gross navigation error to ATC. The first officer detected the error at 40 west and took some time to confirm the error. He then called the captain back to duty, who in turn took some time to confirm the error. Meanwhile, the aircraft was regaining track on its own. Once the captain was clearly aware of the gross navigation error, the aircraft was nearly back on track, and the captain decided not to report the occurrence. It was only after Richair 805 sighted BA Flight 094 and reported the irregularity that ATC became aware of the navigation error. When ATC queried BA Flight 094, the captain immediately confirmed that they had a navigation deviation.

2.0 ANALYSIS

2.1 Introduction

On 11 July 1989, British Airways Flight 094 deviated 120 nm south of its cleared track while flying over the North Atlantic. While off course, BA Flight 094 incurred three risks of collision and two additional losses of separation.

This analysis discusses how the error in navigation occurred, why it remained undetected until the aircraft was 120 nm off course, and the contributing factors.

2.2 The Navigation Error

An FMS/INS input error in Montreal was the initial event in the sequence that caused the near collisions when 5300.0 north, 4000.0 west was inserted instead of the correct 5500.0 north, 4000.0 west.

The first officer could not determine why numeral 53 was programmed instead of 55; however, it was speculated that the number 53 was inserted because the previous north coordinate was also 53. In checking the inputs, the captain used the FMS index page, not the actual coordinate pages and, therefore, missed the input error. He saw the label 55N40 on the index page and that looked correct. This was his routine way of checking a programmed route.

Historically, input errors are the main reason for gross navigation errors over the North Atlantic. The requirement to manually insert latitudes and longitudes into self-contained navigation systems makes such systems prone to input error. On overland routes, this problem is alleviated by using pre-set points which have been stored in the equipment data base. These stored waypoints greatly simplify the data input process by decreasing and simplifying digit input, thus reducing the possibility of input error. Pre-set stored waypoints are not possible for NAT/OTS navigation because of the daily track changes. The only way flight crews can ensure that programming errors do not result in navigation errors is to diligently cross-check their navigation systems.

This programming error became serious when the crew did not detect the deviation from course at 50 degrees west. The crew did not cross-check the INS at 50 west; therefore, they did not discover the programming error.

2.3 Cross-check Procedures En Route

In instructing crews to cross-check en route, the BA L-1011 flying manual clusters all three cross-checks at the waypoint, with no other requirement to cross-check at any other point. If for any reason, any flight crew using this system, misses their cross-checks at a waypoint, the error will not be discovered until the next waypoint. This is precisely what happened in this occurrence. The discovery of the input error came too late to prevent the gross navigation error.

The North Atlantic MNPS Airspace Operations Manual recognizes that distractions can happen and states that distractions must be guarded against. The manual recommends several additional ways of monitoring flight progress to ensure safety if cross-checks over waypoints are missed. One example is, a check and chart plotting of actual position 10 minutes after waypoint passage. This check allows a crew to discover an error and regain track before the error becomes too serious.

There is no doubt that the three cross-checks called for in the BA L-1011 flying manual can prevent a navigation error, but they will do so only if they are conducted at the waypoint. The cross-checks listed in the manual are inadequate because, if they are missed, they allow the aircraft to proceed to the next waypoint before an error is detected. For this reason, the limited cross-checks in the BA L-1011 manual are unsatisfactory. This weakness in the British Airways L-1011 fleet's system of cross-checking contributed to the seriousness of this occurrence.

2.4 Error Reporting

The BA L-1011 flying manual did not clearly and precisely emphasize to the crews the seriousness of a navigation error. This led to this occurrence remaining unreported. It is essential to report gross navigation errors to ATC so they can take positive action to correct the situation. If BA Flight 094 had reported to Gander when they discovered they were off course at 40 west, at the very least, the second risk of collision with Richair 805 may have been avoided. The captain was unclear of his responsibility to report to ATC, and the first officer did not know where the requirement was written; nevertheless, the captain should have exercised good airmanship and reported the error to ATC.

2.5 Air Traffic Control Estimates Versus Pilot Estimates

The crew, in making their 40 west progress, reported a forward estimate for 30 west which was six minutes longer than the controller's estimate. ATC requires that Gander Oceanic controllers request a confirmation if the discrepancy is five minutes or more. Had the estimate been queried, the error may have been detected earlier. This could possibly have prevented the second risk of collision with Richair 805.

2.6 The Use of Labels in the BA L-1011 Flight Management System

The BA L-1011 convention of using a label to program oceanic waypoints, coupled with the way the labels are constructed, leads to a safety problem if a programming error is made. In this case, the crew was looking at the label 55N40 (the actual programmed coordinates were 53 degrees north, 40 degrees west) on the FMS index page. This fooled the crew into thinking they were looking at a correct waypoint. Had a different system of waypoint labelling been used, the crew would have been forced to use the FMS page containing the actual waypoint data. For example, a label like NAT02 could not be mistaken for an actual latitude and longitude. This kind of system may have prevented this occurrence.

2.7 Crew Rest

The crew met the rest requirements as per regulation; however, they started their work at a time after wake-up when most people have finished their workday. At the time of the occurrence, the crew's total sleep amounted to one night in two days. The crew did not believe that they were fatigued.

3.0 CONCLUSIONS

3.1 Findings

1. British Airways Flight 094 deviated 120 nm south of its cleared track while flying eastbound on the North Atlantic.

2. While off course, BA Flight 094 had three serious losses of separation with two other aircraft at FL350.

3. The crew programmed an incorrect waypoint into the INS through the FMS. Fifty-three degrees north, 40 degrees west was inserted instead of the correct 55 degrees north, 40 degrees west.

4. The crew did not detect the programming error when they checked the FMS/INS programming on the ground in Montreal.

5. The crew did not cross-check the INS system at 50 degrees west, and the error remained undetected as the aircraft deviated from its cleared track.

6. The cross-check procedures outlined in the BA L-1011 flying manual could prevent a navigation error, but they were inadequate to protect the crew against distractions at a waypoint.

7. A weakness in the BA L-1011 fleet's existing system of cross-checking contributed to the seriousness of this occurrence.

8. The BA L-1011 flying manual did not emphasize the importance of INS cross-checks.

9. No written instruction to flight crews about reporting navigation errors was contained in the BA L-1011 flying manual.

10. The Number 3 INS system is programmed from the same source and at the same time as the other two systems.

11. The air traffic controller did not query the difference of six minutes between the controller's and the pilot's estimate for 40 degrees west.

12. All three flight crew members on BA Flight 094 were qualified to conduct the flight.

13. British Airways, including L-1011s, were approved by the CAA to fly in MNPS Airspace.

14. The clearances issued by Gander ACC to BA Flight 094, Richair Flight 805, and Aer Lingus 106 were correct and met required separation standards.

15. All clearances were accurately read back by the aircraft.

16. The aircraft was properly equipped to navigate on the North Atlantic and in MNPS Airspace.

3.2 Causes

A two-degree input error, made during programming of the FMS/INS for the North Atlantic crossing, caused the aircraft to begin deviating off course at 50 degrees west longitude. The error went undetected when the INS cross-checks were not conducted at 50 degrees west resulting in a 120 nm deviation south of the assigned North Atlantic Track. A weakness in the British Airways L-1011 fleet's system of cross-checking contributed to the seriousness of this occurrence.

4.0 SAFETY ACTION

4.1 Action Taken

4.1.1 Real-Time Surveillance

At present, there is no real-time air traffic control surveillance system covering the airspace over the North Atlantic, and separation of air traffic is accomplished through procedural controls. This current method of control was not cited as a factor in this incident; however, the installation of a real-time surveillance system could possibly have prevented the losses of separation between the British Airways L-1011 and the other aircraft. A system of this type would have allowed visual monitoring of the traffic by an air traffic controller and, hence, would have provided an increased capability for detecting potential conflicts.

This inability to monitor directly air traffic over the North Atlantic was previously identified in the Canadian Aviation Safety Board (CASB) Report On A Special Investigation Into Air Traffic Control Services In Canada (March 1990). The report observed on the continuing frequency and magnitude of gross navigation errors involving large passenger-carrying aircraft over the North Atlantic Ocean. As a result, CASB recommended that:

> The Department of Transport continue to urgently seek international cooperation through ICAO to implement a real-time surveillance capability over the North Atlantic.
>
> (CASB 90-03)

In its response to Recommendation CASB 90-03, Transport Canada indicated that, as a member of the International Civil Aviation Organization (ICAO) Future Air Navigation System Committee, they had established a developmental program to investigate procedural issues regarding a satellite-based Automatic Dependent Surveillance system (ADS). The ADS system would allow suitably equipped aircraft to automatically transmit their position via a satellite link to a ground monitoring station. Reportedly, aircraft equipped with the appropriate satellite communications systems could begin service in 1991.

4.1.2 Company Procedures

During the investigation, it was noted that discrepancies existed between the North Atlantic MNPS Airspace Operations Manual and the BA L-1011 Flight Manual. Since this occurrence, British Airways has informed the Board that changes to their operating procedures and manuals have been approved by the United Kingdom Civil Aviation Authority (CAA). The following measures have been taken by British Airways to address the identified deficiencies, and these are reportedly now in effect:

a. To eliminate the differences between the British Airways cross-check procedures and those specified in the MNPS, the applicable British Airways' manuals have now been amended to incorporate those items listed in paragraph 1.17.4 of this report;

b. To ensure that inaccurate programming of the FMS does not feed incorrect waypoints to the Number 3 INS, this INS has been separated from the FMS. The Number 3 INS is now programmed by the Flight Engineer independently of the pilot's input to the other two INS through the FMS.

c. To simplify the programming of oceanic waypoints, and at the same time, reduce the likelihood of incorrectly identifying labels associated with the waypoints, British Airways is using pre-stored (within the FMS data bank) North Atlantic waypoints. This labelling conforms to the Aeronautical Radio Incorporated (ARINC) standard. By constructing the planned flight routes using the appropriate labels, the FMS automatically selects the correct latitude and longitude for the waypoints. This process also reduces the number of FMS keyboard entries, further decreasing the chances of programming error.

In addition to the above changes, the CAA has informed the Board that British Airways now maintains progress charts for Atlantic crossings. The aircraft's position is plotted on this chart approximately 10 minutes after passing a waypoint as a check for gross navigation errors. This progress chart is particularly useful in "glass cockpits" where it is very easy to become detached from one's position in the real world and become totally oriented to a coloured line on a screen, irrespective of what that line may represent on the earth's surface.

This report and the safety action therein have been adopted by the Chairman, J.W. Stants, and Board Members.

APPENDIX A

GLOSSARY

ACC	Area Control Centre
ADS	Automatic Dependent Surveillance
ARINC	Aeronautical Radio Incorporated
ATC	air traffic control
BA	British Airways
CAA	Civil Aviation Authority (United Kingdom)
CASB	Canadian Aviation Safety Board
CDU	control and display unit
CVR	cockpit voice recorder
DFDR	digital flight data recorder
EDT	eastern daylight time
FL	flight level
FMS	Flight Management System
FSS	flight service station
HF	high frequency
ICAO	International Civil Aviation Organization
INS	Inertial Navigation System
lat	latitude
long	longitude
MHz	megahertz
MNPS	Minimum Navigation Performance Specifications
N	north
NAT/SPG	North Atlantic Systems Planning Group
NAT/OTS	North Atlantic Organized Track System
NDB	non-directional beacon
nm	nautical mile(s)
QAR	quick access recorder
SELCAL	selective call system
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time
VHF	very high frequency
VOR	very high frequency omni-directional range
W	west
°	degree(s)